Spin polarized tunneling studies in transition metals, alloys, and heavy fermions

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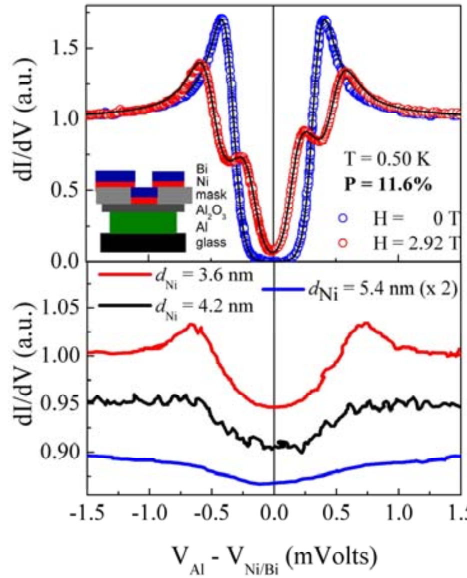
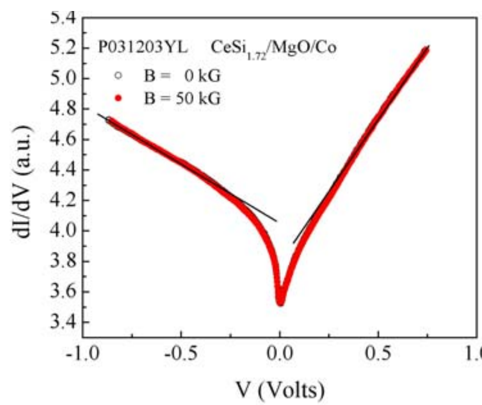
Future information technology is expected to be based on the spin of the electron in addition to its charge. This allows one to have nonvolatile memory as well as reprogrammable logic circuits. Hence it is important to design and understand new materials at the monolayer level. Spin sensitive tunneling is a powerful quantum tool that takes us deep into the spin behavior at atomic or molecular level for the basic understanding of the physical phenomena as well as from the technological point of view.

The apparent mutual incompatibility of superconductivity and ferromagnetism has been discussed for many years, and continues to be an exciting and yet puzzling fundamental problem. We unambiguously demonstrate *for the first time* the coexistence of ferromagnetism and superconductivity in a simple 3d transition metal: directly observing both a superconducting energy gap and conduction electron spin polarization (magnetism) for the same electrons in Ni/Bi bilayers.



Top fig: The curve at 2.9T shows a clear asymmetry, indicating spin polarization (and hence ferromagnetism) in the Ni layer. Inset: junction schematic. **Bottom fig**: the *same* structure also exhibits a clear SC energy gap in Ni/Bi proving that magnetism and superconductivity coexist in this system.



Left: The plot shows not only inelastic excitations in the CeSi layer, but the dip near zero bias indicates the presence of magnetic excitations, and hence ferromagnetism, in the CeSi. Junction structure (side view) is shown at the bottom.

Current electronics is driven by the charge of the electrons. However, future technology may rely on their spin for devices that are faster, denser, cheaper and having nonvolatile memory; besides these can provide reprogrammable logic circuits for say “all-in-one” computers or even cell phone sized multi functional devices. Our research is aimed towards discovering new materials and understanding the physical principles behind these device components and structures at the nano level for shaping future technology, utilizing the technique of quantum tunneling. Along the way we have also discovered the exotic interplay between superconductivity and ferromagnetism and their coexistence, pushing the frontiers of basic knowledge. Students and young scientists are being educated in these forefront science and technology areas.

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In another fundamental study, tunneling from a heavy Fermion Kondo lattice $CeSi_X$ into a superconductor allows us to explore the competition between the RKKY and the Kondo interactions. We have investigated their heavy electron behavior including the observation of inelastic excitations and magnetism in the CeSi layer.

It is pertinent to understand the spin properties of electrons that carry current in spin sensitive devices. We investigated the importance of structural integrity and resulting interface bonding in dictating the magnitude and sign of spin polarization. This is done by tunneling across carefully tailored complex bonded interface between the ferromagnetic material and insulators such as $SrTiO_3$, MgO and Al_2O_3 as tunnel barriers. In addition, the very origin of spin polarization in transition metal ferromagnets is being investigated.

Societal Impact:
Spin based electronics may be the future of storage and telecommunication for faster, denser devices that are nonvolatile, reprogrammable, consuming ultra low power. Our work adds to the knowledge base in addition to opening up the potential for spin sensitive devices as done in the past. The field of research is extensively pursued all over the world including in major industries for its high potential in digital storage application. The PI is an advisor to the research team at the Nanospintronics program in KIST, Korea as well as for two companies. There have been several publications and conference presentations

Education:
Ten high school and undergraduate students have participated in research and carried out their science projects. They are regional finalists (Siemens) and state science fair winners. Most have joined top universities such as MIT, Harvard and Stanford. Two graduate students also have contributed to this work.